Report to the Michigan Legislature on:

Recommended Criteria and Indicators of Groundwater Sustainability for the State of Michigan

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(on behalf of the Michigan Groundwater Conservation Advisory Council)

INTRODUCTION

> *Sustainable use of Michigan's groundwater resources means meeting the needs of the present while not compromising the ability of future generations to meet their needs and recognizing that sustainable use encompasses environmental, economic, and social systems and their contribution to meeting human needs* (GWCAC 2006).

The effective protection, management, and sustainability of groundwater resources has emerged as an extremely important issue in Michigan and the Great Lakes Basin. Groundwater provides 23% of Michigan's public water supply, and 2.7 million residents – mainly in rural areas – obtain their water from domestic wells. The emergence of groundwater sustainability as a priority issue in Michigan was precipitated by conflicts between owners of high-capacity wells and those with domestic small-capacity wells. As a result of these water use conflicts, high-profile court cases were recently litigated over the effects of groundwater withdrawals on flows and levels in streams, inland lakes, wetlands, and the Great Lakes. The absence of science-based policy created a vacuum in which costly litigation became the primary decision framework, resulting in polarized positions. Ultimately, such polarization hinders the ability to build consensus on policy. However, this conflict and the attendant litigation dramatized the need for, and importance of, better information to support sound groundwater sustainability policy.

In response to these issues, the Michigan legislature passed legislation in 2003 to begin addressing groundwater sustainability. Pursuant to Public Act 148 of 2003, the Groundwater Conservation Advisory Council (GWCAC, or Council) was created to evaluate groundwater sustainability and to provide recommendations to the legislature regarding management of groundwater resources in Michigan. The Council, as part of its 2006 report to the Michigan legislature, explicitly recommended that "Michigan should develop a set of criteria and indicators to evaluate the sustainability of Michigan's groundwater use and conduct this evaluation on an ongoing basis. Development of criteria and indicators should be a broad and open process, including subject-matter experts in environmental, economic, and social systems" (GWCAC 2006). The result was the passage of Public Act 34 of 2006, which required the GWCAC to develop indicators and criteria to address the sustainability of groundwater resources in the State of Michigan.

In order to meet this mandate, the Council held a Groundwater Sustainability Workshop on March 26, 2007, to bring together recognized experts in the sectors of environmental integrity, economic development, and social equity to develop a working set of indicators and criteria[1]. The workshop had 3 principal objectives:

- Gather experts to address the issue of groundwater sustainability in Michigan;
- Identify a short (3-5) working list of indicators and criteria for each sector; and,
- Review and vet these short lists among all workshop participants.

[1] The Council, with the assistance of the Institute of Water Research at MSU, originally submitted a proposal to the US EPA to develop a comprehensive, statewide Groundwater Sustainability Indicator System Model to address this mandate. However, the proposal was declined for funding; instead, this one-day workshop was held in its place.

This report summarizes the findings of the March 26 Workshop and provides 6 major recommendations to the Michigan Legislature for the development of 11 groundwater sustainability indicators and 16 measurements with associated criteria to guide the sustainable management of groundwater resources in Michigan.

WORKSHOP OVERVIEW

Forty-four experts and stakeholders from Michigan's environmental, economic, and social sectors attended the day-long Groundwater Sustainability Workshop (Appendix A) held March 26, 2007 at the Egypt Valley Country Club, just outside of the City of Grand Rapids. A wide diversity of interests were represented, including Council members; federal, state and local government officials; academic researchers and professionals; industry leaders; and representatives of non-governmental organizations. Thirteen of the seventeen Council members participated in the workshop. The full workshop agenda is included in Appendix B. Prior to the workshop, attendees were provided with a background document (see Appendix C) that outlined the Council's charge to develop these indicators. It also provided example indicators from the Council's 2006 report to the Michigan Legislature and the 2007 State of the Lakes Ecosystem Conference (SOLEC) indicators of ecosystem condition for the entire Great Lakes region.

Council member and workshop organizer, Dr. Alan Steinman, Director of the Annis Water Resources Institute of Grand Valley State University, welcomed the workshop participants and introduced Senator Patricia Birkholz, who delivered the opening remarks. Senator Birkholz' address was followed by presentations by John Wells of the Minnesota Environmental Quality Board and Sustainable Water Resources Roundtable, and Jim Nicholas of the USGS Water Science Center, which helped set the tone of the workshop and provided critical background information for participants.

Following the presentations, participants worked together to reach consensus on priority groundwater indicators for Michigan. Breakout groups representing environmental, economic, and social sectors identified indicators and criteria for sustainable groundwater development in the State. Steve Gasteyer (University of Illinois), John Wells (State of Minnesota), and Judy Beck (U.S. EPA) were invited to the workshop because of their prior experience with indicator development and helped guide their respective breakout group (Gasteyer: social; Wells: economic; Beck: environmental).

In the final session of the workshop, the entire group reconvened to discuss each breakout group's recommendations and to develop the final list of indicators for each of the three sectors. There was considerable debate within the breakout groups and among all workshop participants regarding the selection of indicators, measurements, and criteria. Workshop participants recognized and agreed that the 11 groundwater sustainability indicators are meant to be dynamic and should be revisited periodically.

GROUNDWATER SUSTAINABILITY INDICATORS AND CRITERIA

The use of science-based indicators is expected to be one of the principal tools in supporting the sustainable management of groundwater and related natural resources in Michigan. Groundwater sustainability indicators are particularly important because groundwater resources are largely out of sight and our knowledge of them is fragmented and incomplete. These indicators provide a science-based foundation on which sustainable groundwater policies can be developed, evaluated, modified, and/or adopted.

Criteria and indicators can be useful tools to evaluate and measure the sustainability of natural resources. Criteria are defined as standards or points of reference that help in choosing indicators; they are more general and less detailed than indicators (Kranz et al. 2004, Steinman et al. 2004). Indicators are defined here as measures that present relevant information on trends in a readily understandable way. Good indicators should be measurable, consistent, based on readily available or obtainable information, and comparable among various geographic regions. Workshop participants were instructed to identify those indicators they believed were most appropriate, irrespective of whether or not relevant data were currently available. For each indicator, a set of specific measurements is selected to provide explicit, quantitative information about that indicator. Comparing measurements over time for specific indicators results in trends, which can be used to assess the sustainability of Michigan's groundwater resources.

I. ENVIRONMENTAL SECTOR

Representatives from the environmental sector identified five indicators of groundwater sustainability (Table 1).

Table 1: Recommended groundwater sustainability indicators and their associated measurements and criteria for the Environmental Sector.

Indicator	Measurement	Criteria
1. Groundwater contribution to stream baseflow	1-1. Change in groundwater contribution over time	1-1. Adequate groundwater discharge to maintain natural flow and temperature regimes
2. Groundwater withdrawals	2-1. Volume of water use by sector	2-1. Efficient use to maintain adequate supply for public and private needs
3. Land use impacts	3-1. % natural land use/land cover 3-2. % impervious surface	3-1. Increase 3-2. Decrease below reference impairment thresholds
4. Groundwater contamination	4-1. Number of at-risk sites	4-1. Decrease
5. Groundwater-dependent natural communities	*Not developed*	*Not developed*

Indicator 1: Groundwater Contribution to Stream Baseflow – Sufficient groundwater should be discharged to streams to maintain natural flow and temperature regimes.

> Measurement 1-1: Change in groundwater contribution over time – Measuring changes in groundwater contribution to baseflow over time is fundamental to the assessment of groundwater sustainability. In areas where groundwater recharge is compromised or excessive withdrawals are occurring, groundwater may not provide adequate discharge to streams or other aquatic ecosystems.

Indicator 2: Groundwater Withdrawals – The volume of groundwater withdrawals should not interfere with the maintenance of an adequate water supply for public and private needs.

> Measurement 2-1: Volume of water use by sector – Tracking trends in the volume of groundwater withdrawals provides valuable information on the efficiency of groundwater use by each sector. Trends in groundwater use can be used to develop models that predict the impacts of new withdrawals on the aquatic system.

Indicator 3: Land Use Impacts – Land use affects the recharge rate of groundwater aquifers, thereby influencing the quantity of this resource. The impact of land use on groundwater quantity can be characterized by two measurements.

> Measurement 3-1: % Natural land cover/land use – Tracking changes in the types of land use that enhance groundwater recharge, such as natural cover, can provide information on the potential for groundwater replenishment. Over time, this measurement can be correlated with the groundwater contribution to baseflow. Increases in these measurement values would be suggestive of groundwater sustainability.

> Measurement 3-2: % Impervious surface – Land use types that promote surface runoff, such as impervious surfaces, hinder groundwater recharge. Tracking changes in these types of land use can provide information on those areas at risk for groundwater shortages. Like Measurement 3-1, this measurement can be correlated over time with the groundwater contribution to baseflow. Decreases in this measurement below accepted reference thresholds for ecological impairment would suggest increased groundwater sustainability.

Indicator 4: Extent and Impacts of Groundwater Contamination – Degradation of groundwater quality can lead to environmental degradation, decreases in water use efficiency, and water use conflicts. The number of contaminated groundwater sites should stabilize and then decline as more sustainable practices are implemented.

> Measurement 4-1: Number of at risk sites – Development of a database to track the number of sites at-risk for groundwater contamination would allow for the detection of trends over time. Contaminated sites could be identified from existing

databases and provide baseline measurements, including Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Leaking Underground Storage Tank (LUST), as well as other state-identified contaminated sites under PA 451 part 201 of 1994.

Indicator 5: Groundwater-Dependent Natural Communities – In surface water systems that are dependent on groundwater discharge, plant and animal communities can be impacted by the degradation of groundwater quality and quantity. Although the workshop participants agreed that this indicator is very important, there were no specific measurements identified to characterize this biological condition. The group discussion raised many concerns, particularly related to whether conditions in a biological community can be attributed clearly to the impacts associated with a change in groundwater resources. Because there are multiple stressors acting on aquatic ecosystems, the stress from a change in groundwater discharge may be indistinguishable and/or undetectable from other stressors. The group concluded that this indicator is critical, but carefully-considered selection of scientifically-sound measurements is essential. Biological metrics, such as the abundance and diversity of groundwater-dependent fish, plants, and invertebrates were suggested. The number and quality of fen communities were identified as another potential measurement. In addition, continued monitoring of stream fishes should be considered as a measurement, given its current status in Michigan law.

No measurements were identified at this time.

II. ECONOMIC SECTOR

Representatives from the economic sector began with the mission of defining the economic value of water. The breakout group identified a lengthy list of potential methodologies for measuring the economic value of water. It was noted that groundwater is a critical resource that is needed for the function of many of Michigan's economic activities across all sectors. Although most economic activities could not function without reliable supplies of water, the economic value of water is not calculated or viewed in the same way as other economic inputs. There was concern expressed about the imposition of cumbersome reporting requirements.

There was a considerable amount of discussion among the full group of workshop participants as to how to translate this list into groundwater indicators. The larger group discussion identified certain gaps that were not addressed by the economic breakout group, including: 1) the tourist economy centered around Michigan's renowned groundwater-fed rivers and lakes; and 2) the sustainable use of Michigan's abundant groundwater resources as a focal point in the vision for Michigan's future economic health. Consensus was reached on three general economic indicators of groundwater sustainability.

Table 2: Recommended groundwater sustainability indicators and their associated measurements and criteria for the Economic Sector.

Indicator	Measurement	Criteria
6. Cost of groundwater by relevant economic sector	*Not developed*	*Not developed*
7. Efficiency of groundwater usage	7-1. Product-output per unit groundwater per sector	7-1. Increase
8. Water usage from alternative sources	8-1. Gallons of water recycled 8-2. Gallons of water used from collection of stormwater	8-1. Increase 8-2. Increase

Indicator 6: Cost of Groundwater by Relevant Economic Sector – The direct costs of water and groundwater from municipal and other sources have important impacts on commercial and industrial usage. The availability of abundant groundwater sources may lower production costs and provide an impetus for businesses to come to or stay in Michigan. Conversely, local limitations on groundwater resources will drive up business costs and hinder economic growth and stability. Although workshop participants discussed this issue extensively, no specific measurements were identified to characterize this indicator within the timeframe of the workshop. Further discussion is required to obtain consensus on measurements for this indicator.

No measurements were identified.

Indicator 7: Efficiency of Groundwater Usage – Encouraging water conservation and increasing the product-output per unit of groundwater in each commercial or industrial sector would promote the sustainability of groundwater resources and allow additional users access to these resources. However, caution must be exercised to ensure that one economic sector of water users does not obtain an unfair advantage at the expense of another sector.

Comment: There was some disagreement as to whether this indicator should be efficiency or gross revenue. This needs to be clarified for the final report—Steinman

Measurement 7-1: Product-output per unit of groundwater use per sector – It is recognized that this measurement does not lend itself to comparisons *among* sectors, given the differences in the products from each respective sector. The critical comparison is within a specific sector over time to detect trends. Specific sectors were discussed, such as agriculture and manufacturing, but time constraints prevented participants from recommending specific sectors for inclusion.

Indicator 8: Water Usage from Alternative Sources – The use of water from alternative sources, such as reused water and/or detained stormwater, will enhance the sustainability of Michigan's groundwater resources. This indicator can be characterized by two measurements, in which increasing trends would indicate sustainable practices:

Measurement 8-1: Gallons of water recycled

Measurement 8-2: Gallons of water used from collection of stormwater

III. SOCIAL SECTOR

Representatives from the social sector identified three indicators of groundwater sustainability.

Table 3. Recommended groundwater sustainability indicators and their associated measurements and criteria for the Social Sector.

Indicator	Measurement	Criteria
9. Public education	9-1. Public knowledge of groundwater resources 9-2. Water resource education 9-3. Local government training	9-1. Increase 9-2. Increase 9-3. Increase
10. Conservation	10-1. Public water systems using groundwater 10-2. Water utilization by sector	10-1. Efficient use to maintain adequate supply for public and private needs 10-2. Unspecified
11. Restricted groundwater access	11-1. Use restrictions due to contamination 11-2. Adverse resource impacts (ARIs) 11-3. Water Use conflicts	11-1. Decrease 11-2. Decrease 11-3. Decrease

Indicator 9: Public Education – This indicator can be characterized using three measurements. For each of these measurements, an increase over time would be indicative of practices that promote groundwater sustainability.

Measurement 9-1: Public knowledge of groundwater resources – Surveys conducted at 3-5 year intervals could measure the extent of relevant knowledge and identify gaps. Survey questions could address issues associated with the quality and protection of drinking water sources, potential impacts of land use changes on groundwater quantity and quality, and the ecological and economic significance of groundwater.

Measurement 9-2: Water resource education – This measurement could include the number and percentage of public and private schools offering water resource education programs.

Measurement 9-3: Training of local government officials – This measurement most likely would include the number and percentage of officials receiving training in the sustainability of groundwater resources. This measurement would be geared toward non-specialist local officials and planners, rather than resource-related specialists (e.g., drain commissioners).

Indicator 10: Conservation – This indicator characterizes the efficiency of groundwater use through the tracking of trends in two measurements. The direction of these trends can

be used to demonstrate whether the use of groundwater is maintaining an adequate supply of groundwater for public and private needs.

Measurement 10-1: Public water systems using groundwater – Increasing the efficiency of groundwater use by public water system users could enable a greater number of systems to use and sustain the same resource. Conversely, groundwater shortages could cause public water suppliers to seek alternative supply sources.

Measurement 10-2: Water use by sector – Identifying trends in water use by SIC code can provide useful information on water use efficiency. Some uses of groundwater are considered consumptive; that is, after the water is withdrawn for use, it is no longer available for recharge back to the aquifer. Other uses are partially non-consumptive. A decline in groundwater use could indicate either greater efficiency or groundwater shortages.

Indicator 11: Restricted Access to Groundwater Resources – Restrictions on the functional access to groundwater resources may indicate problems in the protection, use, or management of groundwater. As water use becomes more efficient and sustainable, restrictions on functional access should decline. This indicator can be characterized by three measurements.

Measurement 11-1: Use restrictions as a result of contamination – This measurement counts the number of locations where groundwater is not available as a result of contamination and its potential adverse impact on public health. An example of this measurement is a restriction on well withdrawals because the water contains nitrate levels that exceed regulatory limits.

Measurement 11-2: Adverse resource impacts (ARIs) – This measurement counts the number of times that there is a finding of an adverse resource impact (ARI) by the Michigan Department of Environmental Quality.

Measurement 11-3: Water use conflicts – Conflicts over groundwater use can arise through actual or perceived inefficient use of the resource. This measurement counts the number of cases in which government mediation is required to resolve a user conflict.

SUMMARY

The development of indicators to track the status and trends of environmental resources is an important emerging issue. The sustainability of groundwater resources poses a serious challenge to state and local policymakers, given the diverse background and interests of stakeholders, the complexity of the subject matter, and a paucity of scientifically-sound data. However, the environmental, social, and economic importance of groundwater, and the increasing number of groundwater conflicts, necessitates the development of a robust science-based framework to support resource sustainability. The Groundwater Conservation Advisory Council (GWCAC),

with the help of multiple sector experts, met the challenge of developing this framework. Principles outlined in the GWCAC 2006 report to the Michigan legislature (GWCAC 2006) guided them in the development of a holistic and practical set of groundwater sustainability indicators, which include the following:

- Indicators must be developed at local and regional scales.
- Indicator development should support an informed debate about groundwater use and its relationship to sustainability.
- Indicators should consider all aspects of resources, to provide a balanced outlook.
- The number of indicators should be simple and understandable to all interested parties, and limited in number.
- Indicators should be quantifiable and based on known scientific data or understanding where possible.

Each indicator provides some information regarding the sustainability of groundwater resources in Michigan. This coherent set of indicators establishes a framework to support a holistic assessment of the sustainability of groundwater resources. However, it is important to recognize that the identification of sustainability indicators is a dynamic and living process that requires periodic review and re-evaluation. This workshop has initiated this process, but the findings and results presented here should be viewed as preliminary, not final.

RECOMMENDATIONS

1) Adopt the recommended set of sustainability indicators described in this report in conjunction with an implementation program to determine the current status of these indicators.
   The implementation program would measure and track future changes to determine whether the use of Michigan's groundwater resources is sustainable over time.

2) Create/appoint a groundwater sustainability indicators working group to refine the indicators and measures identified in this report.
   This working group should include core staff from MDEQ, MDNR, and MDA, as well as select individuals from the private and public sectors who have an understanding of groundwater based on expertise and/or experience.

3) Require the working group to meet annually to review the sustainability indicators, assess data trends, and modify or add indicators, as needed, based on sound science research and knowledge.
   Consistent measurement of these indicators over time will provide critical information on whether Michigan's trends are consistent with or diverge from the sustainability of groundwater resources in Michigan. These indicators and their associated measurements should be refined over time as more information becomes available, society's values evolve, and trends become apparent.

4) Refine the criteria for groundwater sustainability indicators, where appropriate.

For some indicators, it may be possible to add numeric targets (for instance, % change) to the criteria to define groundwater sustainability more clearly.

5) Aggregate the key indicators from the environmental, social, economic sectors into a composite set of comparative metrics to determine the overall status of groundwater sustainability.

A composite sustainability assessment provides a holistic assessment of groundwater status. Without composite indicators, results from individual sectors could be misleading; for example, a case where the improvement in use efficiency in one sector precipitates a decline in use efficiency in another sector.

6) Collect, generate, and analyze relevant data to assist the evaluation and effective management of statewide groundwater resources for future generations to come.

Although the GWCAC has collated information on Michigan's groundwater resources, data gaps remain in ascertaining the current conditions of groundwater resources. For example, the total decrease in the volume of groundwater stored in aquifers as a result of withdrawals has not been calculated, nor have trends in groundwater storage. Likewise, the decrease in streamflow resulting from large, long-term withdrawals of groundwater has not been calculated, nor have the related trends. Filling these data gaps is critical to answering questions about the use of Michigan's groundwater resources and the sustainability of these valuable resources over time.

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APPENDIX A

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APPENDIX B

GROUNDWATER SUSTAINABILITY WORKSHOP

DATE: MARCH 26, 2007
LOCATION: EGYPT VALLEY COUNTRY CLUB
GRAND RAPIDS, MICHIGAN

AGENDA

Rationale:

- PA 34 of 2006 requires the Groundwater Conservation Advisory Council to develop indicators and criteria to address the sustainability of groundwater resources in the State of Michigan. In order to meet this mandate, a workshop is being organized to bring together experts in the sectors of social equity, economic development, and environmental integrity to develop a working set of indicators and criteria. **As a recognized expert in one of these sectors, you are being invited to attend and participate in this important workshop.**

Specific Meeting Objectives:

- Gather experts to address issue of groundwater sustainability in Michigan
- Identify a short (3-5) working list of indicators and criteria for each sector; and
- Review and vet these short lists among all workshop participants
- These working lists will form the basis for our recommendations to the Michigan Legislature

Monday, March 26th

8:45 – 9:15	Continental Breakfast
9:15– 9:35	Welcome, Introductions, and Review Workshop Objectives/Agenda • Welcome and participant introductions and meeting objectives/agenda – *Alan Steinman, Annis Water Resources Institute-GVSU*; • Opening Comments – *Senator Patricia Birkholz (invited)*
9:35 – 10:15	Overview of Sustainability Indicators and Criteria • General background – *John Wells, Water and Sustainable Development Director, Minnesota Environmental Quality Board* • Question and answer session
10:15 – 10:35	Overview of Michigan Groundwater • General background – *Jim Nicholas, USGS* • Question and answer session
10:35 – 10:50	Specific Guidance on Breakout Sessions • Charge to each group – *Al Steinman* • Question and answer session – *Group*

10:50 – 11:10	BREAK
11:10 – 1:00	Breakout Sessions (Environment, Social, and Economic Sectors) • Select note-taker and reporter – *Each Sector* • Discussion of Criteria and Indicators – *Each Sector*
1:00 – 1:30	**WORKING LUNCH** • Continue work in break out sessions – *Each Sector* • Directed questions – *Each Sector*
1:30 – 2:00	Reports from Breakouts on Recommended Criteria and Indicators • Social Sector • Economic Sector • Environmental Sector
2:15 – 3:15	Group Discussion • Criteria and Indicators from each Sector • Consensus? • Concerns?
3:15 – 4:00	Breakout Group Wrap-Up • Assimilate group discussion information – *Each Sector* • Consensus on final criteria and indicators– *Each Sector*
4:00 – 4:30	Group Wrap-Up
4:30	Adjourn

APPENDIX C

Groundwater Sustainability Workshop
March 26, 2007

A Workshop to Develop Indicators of Sustainable Groundwater Use in the State of Michigan

Background Information

(for reading prior to Workshop)

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I. WORKSHOP BACKGROUND

The effective protection, management, and sustainability of groundwater resources have emerged as an extremely important issue in Michigan and the Great Lakes Basin. Groundwater provides 23% of Michigan's public water supply, and 2.7 million residents – mainly in rural areas – obtain their water from domestic wells. The emergence of groundwater sustainability as a priority issue in Michigan was precipitated by conflicts between owners of high-capacity wells and those with domestic small-capacity wells. As a result of these water use conflicts, high-profile court cases were recently litigated over the effects of groundwater withdrawals on flows and levels in streams, inland lakes, wetlands, and the Great Lakes. The absence of science-based policy created a vacuum in which costly litigation was substituted, and positions became polarized. Ultimately, polarization hinders the ability to build consensus on policy. However, this conflict and the attendant litigation dramatized the need for, and importance of, better information to support sound groundwater sustainability policy.

The Michigan Legislature initially responded to groundwater use conflicts by passing new laws in 2003 to inventory and map Michigan groundwater resources, create the Groundwater Conservation Advisory Council (GWCAC, or Council) (2003 PA 148), and address water use conflicts (2003 PA 177). With the assistance of the Council, legislation establishing a comprehensive framework for the management of water resources in Michigan was signed into law on February 28, 2006. The Council is charged with developing policy recommendations to address groundwater sustainability in the state by July 1, 2007 (2006 PA 34).

This legislative mandate presents a unique opportunity to provide the Michigan policy-making process with a science-driven mechanism that will generate relevant information squarely focused on stakeholder and public policy needs. This process will result in the creation of state groundwater sustainability indicators.

II. SUSTAINABILITY AND INDICATOR BACKGROUND

We use the definition of Alley et al. (1999) to describe groundwater sustainability: development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. The Council, as part of its 2006 report to the Michigan legislature, explicitly recommended that "Michigan should develop a set of criteria and indicators to evaluate the sustainability of Michigan's groundwater use and conduct this evaluation on an ongoing basis. Development of criteria and indicators should be a broad and open process, **including subject-matter experts in environmental, economic, and social systems"** (GWCAC 2006; emphasis added).

Criteria and indicators can be useful tools to evaluate and measure the sustainability of natural resources. Criteria are defined as standards or points of reference that help in choosing indicators; they are more general and less detailed than indicators (Kranz et al. 2004, Steinman et al. 2004, Water Resources IMPACT 2006). Indicators are defined here as measures that present relevant information on trends in a readily understandable way. Good indicators should be measurable, consistent, based on readily available or obtainable information, and comparable among various geographic regions (Table 1).

Table 1. Hypothetical examples of criteria and associated indicators for the goal of providing water for the environment. *Source: GWCAC 2006.*

Types of Criteria	Associated indicator
Target	10% increase in water for environment
Direction of change	Increase water for environment
Category for potential directional goal or target	Adequate water supply and timing for environment

III. PROGRESS TO DATE

The development of indicators to track the status and trends of environmental resources is an emerging trend. Recent efforts by the Heinz Center and USEPA (H. John Heinz III Center 2002, USEPA 2003) have focused on national indicators. However, there is a growing recognition that indicators, to be effective, must be developed at the local and regional scales (USEPA 2003, Barlow et al. 2004).

III.A. Groundwater Conservation Advisory Council

The Council, as part of its 2006 report to the Michigan legislature (GWCAC 2006), included example indicators of sustainable groundwater development in Michigan (Table 2). It is recognized that these indicators vary in their specificity, but the goal here is to stimulate discussion about which, if any, may help the State of Michigan as it debates groundwater sustainability. These examples may serve as a starting point for the workshop discussions.

III.B. State of the Lake Ecosystem Conference (SOLEC) Indicators

The State of the Lake Ecosystem Conference (SOLEC) identifies indicators for the entire Great Lakes region. We have identified four indicators from their 2007 draft that are relevant to our process. They are included below, slightly modified for our purposes. The detailed SOLEC report can be accessed at:
http://www.solecregistration.ca/documents/Draft%20Great%20Lakes%20Ecosystem%20Status%20and%20Trends%20report%20Nov%2006.pdf

A workshop was held on November 3, 2006 to further describe SOLEC indicators. Recommendations on the indicators were provided from Judy Beck, (U.S. EPA), Victoria Pebbles (Great Lakes Commission), Dale Phenicie (Council of Great Lakes Industries), and Melissa Simon (U.S. EPA). The most recent output from that workshop is provided in Appendix A of this document.

Table 2. Example indicators of sustainable groundwater development for Michigan. *Source: GWCAC 2006.*

Sector Type	Example Indicator
Ecological System	**Streamflow**: Mid-summer discharge and timing of flows at key stream gages.
	Groundwater Level: Late-summer water levels at key monitoring wells.
	Water Quality: Number of known contaminated sites discharging goundwater to surface water.
Social System	**Public Health**: Number of domestic wells with nitrate concentration exceeding drinking water maximum contaminant level.
	Education: Number of elementary school systems including water resources or conservation in their curricula.
	Conservation: Number of local governments implementing water conservation or management plans.
Economic System	**Sales**: Economic value of sales from irrigated agriculture and/or irrigated golf courses.
	Conservation Investments: Economic value of investments to reduce water use by use sector.
	Demand Forecasting: Number of public-supply systems doing demand forecasting.
	Lost Investments: Number and economic value of supply wells abandoned because of contaminated groundwater.

Draft SOLEC Indicators:

III.B.1. Water Withdrawals (Indicator #7056: status mixed/unchanging)

The stated purpose of this indicator is to use the rate of water withdrawal to help evaluate the sustainability of human activity in the Great Lakes region. Unfortunately, this indicator does not discriminate between surface water and groundwater withdrawal. Figure 1 breaks down all water withdrawals in the Great Lakes basin, but it is still useful for discussion purposes. Groundwater was withdrawn at a rate of 1,541 MGD in 2000, compared to a total withdrawal of 46,046 MGD, or ~3.3% of total.

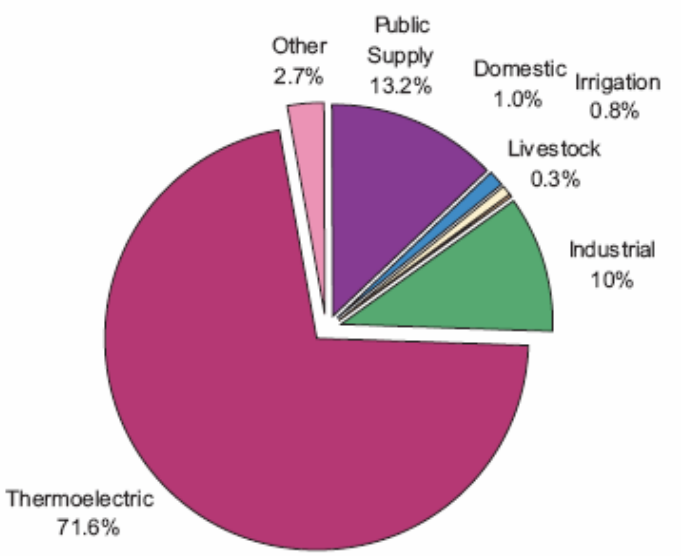

Figure 1. Water withdrawals in the Great Lakes basin in 2000, by category as percentage of total. *Source: Great Lakes Commission 2004.*

In Michigan alone, groundwater accounts for ~5% of the total water withdrawn, with public water supply and irrigation accounting for the majority of the groundwater withdrawals (Figure 2).

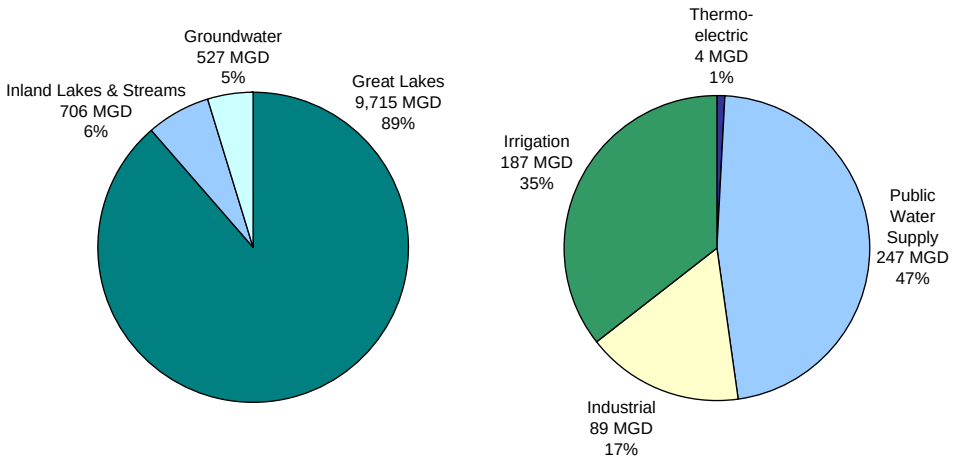

Figure 2. Sources of water for major water withdrawals in Michigan in 2004 (left) and groundwater withdrawal by major water use sectors (right). *Source: MDEQ 2006.*

There is growing concern over the depletion of groundwater resources, which cannot be replenished following withdrawal with the same ease as surface water bodies. The overall rate of withdrawal may not have much effect on the Great Lakes basin or on an individual state as a whole, but high-volume withdrawals may outstrip natural recharge rates in specific locations. Interestingly, the overall withdrawal of water from the Great Lakes has been decreasing; US withdrawals have declined by >20% since 1980 while Canadian withdrawals have declined by ~30% since the 1990s. However, in the immediate future, new pressures are expected from: 1) increased demand from communities bordering the basin, especially in locations where existing water supplies are scarce or of poor quality; and 2) global climate change, which may result in lower water levels.

III.B.2. Groundwater and Land: Use and Intensity (Indicator #7101: status undetermined)

The stated purposes of this indicator are: 1) to measure land and water use and intensity; 2) to infer the potential impact of land and water use on the quantity and quality of groundwater resources and evaluate groundwater supply and demand; and 3) to track the main influences on groundwater quantity and quality, such as land and water use to ensure sustainable high quality groundwater supplies.

Land use directly influences the ability of precipitation to recharge shallow aquifers. For example, urban development and its associated impervious surfaces (e.g., roads, buildings) intercept precipitation and facilitate the movement of water off the land as surface runoff, thereby reducing groundwater recharge to shallow aquifers. In contrast, some agricultural land use and forested areas protect groundwater recharge.

III.B.3. Baseflow due to Groundwater Discharge (Indicator #7102: status mixed/deteriorating)

The stated purposes of this indicator are: 1) to measure the contribution of baseflow due to groundwater discharge to total streamflow and 2) to detect impacts of anthropogenic factors on the quantity of the groundwater resource.

Baseflow due to groundwater discharge to the rivers, inland lakes, and wetlands of the Great Lakes is a significant and often major component of streamflow, particularly during low flow periods. The health of aquatic species and habitat is frequently dependent on water flow, level, and temperature—all of which are satisfied, at least in part, by baseflow. Therefore, groundwater discharge that results in baseflow is critical to the maintenance of water quantity and quality and the integrity of aquatic species and habitat. All groundwater discharge contributes to baseflow, but not all baseflow is the result of groundwater discharge.

Variability in baseflow is apparent throughout the Great Lakes region, but further analysis is needed to differentiate between the component of baseflow that is due to groundwater discharge and the component that is due to delayed flow through upstream lakes and wetlands. This latter component appears to have a significant influence over extensive portions of the Great Lakes basin.

The baseflow index is the ratio of baseflow to total flow volume for a given year. While the groundwater component of streamflow (baseflow) is large, the actual percentage is uncertain. SOLEC estimated that the contribution of baseflow due to groundwater discharge is ~60% for Lakes Huron, Michigan, and Superior, and ~50% for Lakes Erie and Ontario. In contrast, Neff et al. (2005) estimated that ~80% of the annual streamflow in Michigan's lower peninsula results from groundwater discharge (Figure 3 below; GWCAC 2006). These differences relate to how the baseflow index is calculated.

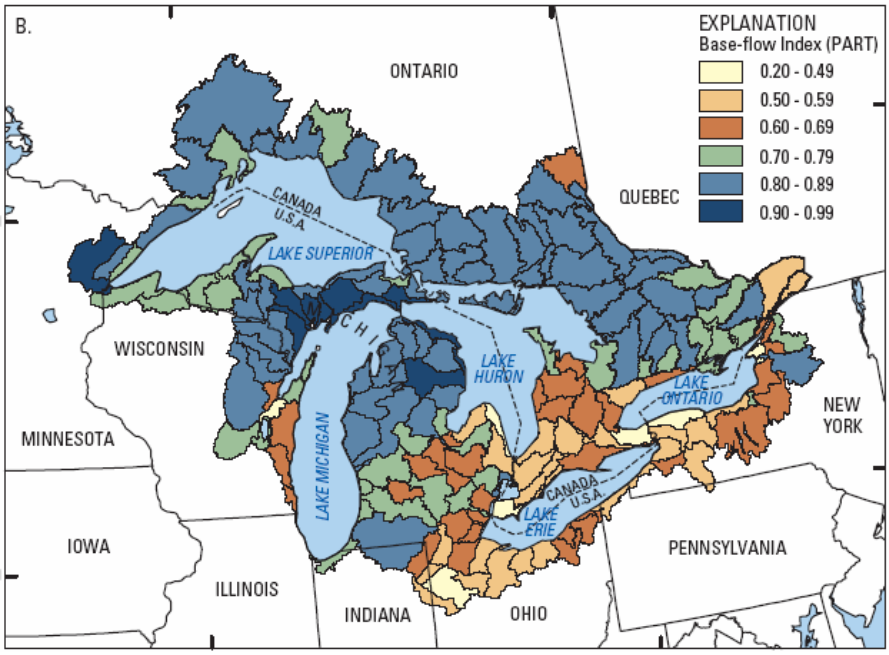

Figure 3. Baseflow is a large percentage of the total annual streamflow in Michigan. Baseflow index (BFI) can be read as the percent of total annual streamflow that is baseflow. Thus a BFI of 0.79 means that 79 percent of the total annual streamflow is baseflow. *Source: USGS Scientific Investigations Report 2005-5217.*

III.B.4. Groundwater-Dependent Plant and Animal Communities (Indicator #7103: status undetermined)

The stated purposes of this indicator are: 1) to measure the abundance and diversity, as well as presence or absence, of native invertebrates, fish, plant, and wildlife (including cool-water adapted frogs and salamanders) communities that are dependent on groundwater discharges to aquatic habitat; 2) to identify and understand the consequence of any water quality deterioration for animals and humans, as well as changes in the productive capacity of flora and fauna dependent on groundwater resources; 3) to use biological communities to assess locations of groundwater intrusions; and 4) to infer certain chemical and physical properties of groundwater, including changes in patterns of seasonal flow.

The integrity of larger water bodies can be linked to the biological, chemical, and physical integrity of the smaller water bodies that feed them. Many of these smaller systems are fed by groundwater. As a result, groundwater discharge to surface water becomes cumulatively more important when considering the quality of water entering the Great Lakes. The identification of groundwater-fed streams and rivers will provide useful information for the development of watershed management plans seeking to protect these sensitive ecosystems.

Human activities can change the hydrological processes in a watershed, resulting in changes to recharge rates of aquifers and discharge rates to streams and wetlands. This indicator can serve to identify organisms at risk because of human activities, and can be used to quantify trends in communities over time.

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APPENDIX

(SOLEC Sustainability Indicator Descriptions)

Ground Surface Hardening (Indicator # 7054)

Measure
Percentage of land that is covered by buildings, roads, parking lots and other hardened surfaces.

Purpose
To indicate the degree to which development is affecting natural water drainage and percolation processes and thus causing erosion, and other effects through high water levels during storm events and reducing natural ground water regeneration processes.

Ecosystem Objective
Sustainable Development

Endpoint
Imperviousness mitigated through land management engineering (storm ponding, swells, etc.)

Features
This indicator is related to land conversion indicator for new development. It is also is expected to be indirectly proportional to the amount of high density development taking place, although low density sprawl that includes shopping malls etc. may be similar to high density imperviousness

Last Revised

Water Withdrawal (Indicator # 7056)

Measure
Water use per capita in the Great Lakes basin.

Purpose
To assess the amount of water used in the Great Lakes basin per capita, and to infer the amount of wastewater generated and the demand for resources to pump and treat water.

Ecosystem Objective
Sustainable development is societal goal for the Great Lakes basin.

Endpoint
Resource conservation means reducing the amount of water that is used and the amount of wastewater that results from that water use. Current North American water use rates are in excess of 300 liters per day - reducing that by 50% is desirable and consistent with some European countries.

Features
The indicator provides a quantitative measure of the rate at which natural resources are being used. For example, high levels of water use results in considerable wastewater pollution that results in degraded water quality, as well as increased demand for energy to pump and treat water. The indicator is a gross measure of water supplied through water supply facilities in a jurisdiction divided by the total number of people in the jurisdiction.

Last Revised
Feb. 16, 2000

Concept of grey water reuse is missing here, unclear about ground or surface water? Should Annex 2001 be referenced??

Recommendations

1. A better measure for this indicator might be the cumulative amount of withdrawals excluding withdrawals for hydroelectric use) - in excess of 100,000 gallons per day (379,000 liters per day) or greater average in any 30-day period - per annum.

2. A more appropriate Purpose for this indicator would be: to assess the amount of water used in the Great Lakes basin. The amount of wastewater generated and the amount pumped and treated can be calculated from the annual withdrawal amounts for public supply.

3. The Endpoint could be described as follows: resource conservation means reducing the amount of water that is used and the amount of wastewater that results from that agriculture, industrial and public supply water use.

4. Here are some additional Features that could be included: The Great Lakes Commission serves as the repository for the Great Lakes Regional Water Use Database since 1988. Working with the jurisdictions, the Commission tracks water use in seven categories: public water supply, self-supply domestic (residential, commercial and institutional), irrigation, livestock, industrial (manufacturing and mining), thermoelectric power (fossil fuels plants), thermoelectric power (nuclear plants), and self-supply other. The Commission is committed to supporting the Regional Water Use Database until the Regional Water Management fully establishes the regional water management regime.

Groundwater and Land: Use and Intensity (Indicator # 7101)

Measure
Water use and intensity and land use and intensity.

Purpose
This indicator measures land use and water use and intensity within political sub-divisions (or watershed boundaries) and is used to infer the potential impacts of these practices on the quantity and quality of the groundwater resource. Specifically referring to water use, the indicator also measures supply versus demand issues by assessing the reconstruction of water wells and the construction of new wells.

Ecosystem Objective
Groundwater quantity and quality remain at, or near, natural conditions.

Endpoint
Monitoring of groundwater quantity and quality in the most stressed of the sub-divisions does not detect the deterioration of these conditions.

Features
Land use is a measure of the primary use of the land (e.g., percentage of an area occupied by livestock feedlot operations) and land use intensity is the intensity of this use (e.g., head of feedlot cattle per hectare). Water use is a measure of the primary use of all constructed water wells (e.g., the percentage of all wells that are constructed for livestock watering) and water use intensity of withdrawals from these wells (e.g., the equivalent annual depth of water use for livestock watering). The intra-annual variability of water use intensity is also significant. For example, municipal water use is modestly variable during the year while the use of water for livestock is more temperature dependent and the use of water for irrigation is episodic. The reference watershed sub-divisions should be sufficiently large to ensure the availability of data and sufficiently small to ensure that contrasts in the potential impacts are not masked by averaging. Water use that is consumptive (e.g., irrigation) can result in diminished baseflows and impacts downstream water supplies and aquatic habitat. Water use that is not consumptive can result in the degradation of water quality (e.g. water used for municipal drinking water). Supply versus demand issues are expressed in the reconstruction of water wells; for example, in the deepening of existing wells or replacement of existing wells with larger capacity wells. Patterns in this practice may indicate a diminished supply due to climatic factors or adjacent land or water use, an increased demand at the well and variations in the quality of the supply or the quality requirements of the demand. All of these causes may be evidence of changes in the sustainability of the groundwater resource. In some cases and jurisdictions, it may not be possible to directly determine water use and intensity. Under these conditions, it may be necessary to infer water use and intensity from land use and related information.

Last Revised
Mar 25, 2004

Recommendations

1. This indicator needs a base line to measure unsustainable rates. The endpoint should not be detection - drawdown should not affect water quality, stream habitat/ecosystem, lake levels and have a margin of error for possible climate change. One thing to be included in the data for this indicator is the USGS' recent study of ground water flow models which uses Lake Michigan as a pilot. They look at past data, withdrawal from both bedrock and glacial deposit aquifers, and areas where draw down has created a problem. This study will yield scientific data while the Great Lakes Charter Annex 2001 proposed agreement and a number of new state laws will ensure close tracking of withdrawals.